

BIOLOGY OF *PHYLACTEOPHAGA FROGGATTI* RIEK (HYMENOPTERA: PERGIDAE) AND ITS PARASITIDS IN SOUTH AUSTRALIA

by T. A. THUMLERT & A. D. AUSTIN*

Summary

THUMLERT, T. A. & AUSTIN, A. D. (1994) Biology of *Phylacteophaga froggatti* Riek (Hymenoptera: Pergidae) and its parasitoids in South Australia. *Trans. R. Soc. S. Aust.* 118(2), 99-113, 31 May, 1994.

Information is presented on the biology of *Phylacteophaga froggatti* Riek (the leaf-blister sawfly), an emerging pest of plantation and ornamental eucalypts in south-eastern Australia. The range of eucalypt species attacked, the extent of tree damage, seasonality, fecundity and longevity of *P. froggatti* are investigated for populations in the Adelaide region. The hymenopteran parasitoids associated with *P. froggatti* are reviewed. An illustrated key to the 17 species encountered in the Adelaide region is presented, along with notes on their biology, relationship with their host, and species recorded from other parts of Australia.

KEY WORDS: *Phylacteophaga froggatti*, Pergidae, parasitoids, hyperparasitoids, Braconidae, Ichneumonidae, Chalcididae, Elasmidae, Encyrtidae, Eulophidae, Eupelmidae, Pteromalidae.

Introduction

Phylacteophaga froggatti Riek, the leaf-blister sawfly, is a native leaf-mining species that is generally restricted in distribution to the south-eastern and south-western parts of the continent (Riek 1955; Benson 1963; Farrell & New 1980; Curry 1981). Larvae feed on a range of eucalypt species by mining the mesophyll layer between the upper and lower epidermis of large leaves. This pattern of feeding results in characteristic oval or elongate, brown blisters, which are most common on the lower branches of young trees (Farrell & New 1980; Nuttall 1985). Heavy infestations of *P. froggatti* cause substantial loss of photosynthetic area, resulting in stunted growth or death of trees. This damage is of most concern where large numbers of saplings exist in a confined area, such as eucalypt plantations, ornamental eucalypts in parks and gardens, and potted trees in outside nurseries.

In 1985 *P. froggatti* was accidentally introduced into New Zealand where it has become a serious pest of eucalypt forests and ornamental trees (Nuttall 1985; Kay 1986). This has led to the importation and release of two species of braconid wasp from Australia in an attempt to control this sawfly biologically (Austin & Faulds 1989; Faulds 1990).

Given the pest status of *P. froggatti*, relatively little work has been undertaken on its biology or that of its parasitoids. Other than the work of Farrell & New (1980), who provide a detailed account of some aspects of the biology of *P. froggatti* in the Melbourne area, the species has received only anecdotal attention (Froggatt 1899; anon. 1950; Riek 1955, 1970; Moore 1966; Curry 1981; Naumann 1983; Bungey 1986). Information on its parasitoids is even more limited.

Farrell & New (1980) record some observations on the development and mode of parasitism for two species, *Bracon* sp. and *Cirrospilus* sp. in the Melbourne area, while other workers have simply listed the species reared (Moore 1966; Curry 1981; Bouček 1988). In these studies no more than six species have been recorded and, with the exception of Bouček (1988), the accuracy of species identifications is questionable. More recently, Austin & Faulds (1989) have described two species of *Bracon* that have been introduced into New Zealand, while Faulds (1990) has reported the release and establishment of these species and discussed their potential for controlling *Phylacteophaga*.

The aim of the present study is to document more fully the biology of *P. froggatti*, focusing on aspects that have been largely neglected by previous workers. At the same time, detailed information is presented on the large parasitoid complex associated with *P. froggatti* in the Adelaide region. An illustrated key to their identification, as well as notes on their taxonomy, biology as either primary or hyperparasitoids, immature stages and seasonality are presented as a prelude to future studies on the ecology and possible control measures of this emerging eucalypt forest pest.

Materials and Methods

Field sites

Eucalypt trees infested with larvae and pupae of *P. froggatti* were monitored at several sites in the Adelaide region, viz., from the western coastal suburbs (Dover Gardens), city parklands and adjacent suburbs (Sturt), and Lobethal-Woodside area (Adelaide Hills), between August 1990 and July 1991. The first two sites comprise mostly ornamental trees (immatures of numerous species) in parks and along roadsides, while the latter site is semi-rural and comprises both ornamental trees

* Department of Crop Protection, Waite Campus, University of Adelaide, Glen Osmond, S. Aust. 5064

and naturally growing trees in paddocks and along roadside verges (mostly *Eucalyptus camaldulensis*, *E. cladocalyx* and *E. leucocylon*). The climate of the first two sites is very similar with average monthly maximum and minimum temperatures of 23°C and 13°C, while the Lobethal-Woodside site has average monthly maxima and minima of 21°C and 8°C. The average annual rainfall for these two areas is substantially different (Adelaide 585mm; Lobethal 888mm).

Laboratory rearing

Infested branches, mostly of *E. camaldulensis*, were collected from the field, placed in plastic bags and returned to the laboratory. They were placed in containers of water at room temperature or constant 20°C and *P. froggatti* allowed to develop. Leaves with larvae, pupae and/or developing parasitoids were backlit with an optical fibre light to determine the exact stages present and observe their development. Most parasitised and unparasitised pupae were separated into 5 cm dia. plastic containers and allowed to complete development. Once emerge, adult *P. froggatti* and parasitoids were kept alive by supplying them with a smear of honey and water via a saturated cotton roll pushed through the lid of a small glass vial. Virgin female *P. froggatti* were sometimes isolated from males as soon as they emerged to provide individuals for laboratory experiments.

Fecundity and longevity

Virgin female *P. froggatti* which had emerged over a 24 hour period were held at constant 20°C with honey and water supplied. Ten individuals, randomly selected each day, were measured for body length, killed in 70% EtOH, squashed on a microscope slide and the number of fully developed eggs counted.

To determine the longevity of *P. froggatti*, adult females were kept in 20 cm diameter plastic cages and their survival monitored twice daily until all wasps had died. Longevity was compared for 1) virgin or mated females, 2) with or without water and honey, and 3) at five temperatures (10, 15, 20, 25, 30°C). Ten females that had emerged within a 12 hour period were randomly selected from stock cages and transferred into experimental containers. Three replicates were run for each of the above 20 treatments. Honey or water were not supplied during mating to those which went into the 'no food' treatments. All cages were held at 12:12 h photoperiod in temperature cabinets with $\pm 0.5^\circ\text{C}$ temperature ranges. The mean survival time for each treatment was calculated and plotted against temperature, and the regressions analysed using a 2-tailed F-test.

Taxonomy and scanning electron microscopy

Terminology for morphological structures generally follow Gauld (1984) and Gauld & Bolton (1988) for

ichneumonid and braconid wasps and Bouček (1988) for chalcidoids. Where necessary, morphological structures referred to in the key are indicated on the figures. Voucher material of all species have been lodged in the Waite Campus insect collection, University of Adelaide.

Specimens for SEM examination were killed and washed in a strong detergent solution before being dehydrated in 100% EtOH and critical point dried in an Emscope CPD 250. They were coated twice with carbon and gold/palladium before being examined under a Phillips 505 Scanning Electron Microscope.

Results and Observations

Taxonomy of Phylacteophaga

The taxonomy of *Phylacteophaga* species is confused and requires urgent study. Nominally, only one species, *P. eucalypti* Froggatt, is recognised which has been divided into four subspecies (*P. e. eucalypti*, *P. e. froggatti* Riek, *P. e. tasmanica* Riek and *P. e. occidentalis* Benson) based on colour and size (Benson 1963). At least two of these subspecies (*P. e. froggatti* and *P. e. occidentalis*) occur sympatrically and may therefore represent distinct biological species (Naumann 1983). However, of the several hundred specimens reared from leaf mines by us during 1990-91 all belong to the one colour form, that of *P. e. froggatti* Riek (i.e. antennal scape and pedicel and scutellum of female pale yellow to orange-yellow). Furthermore, mating of field-collected material in the laboratory was always successful, supporting the premise that either only one species is present or one is dominant in the Adelaide region. Because all recent authors (e.g. Farrell & New 1980; Curry 1981; Faulds 1990) have adopted species level status for the subspecies *P. e. froggatti*, this approach will be used here to save confusion.

Mating

In the field, males were often observed perched on the dorsal surface of leaves with their body held at 45° above the surface, in the vicinity of ovipositing or resting females, or flying in small swarms of 5-10 individuals, close to leaves where mating pairs were perched. Copulation is strophandous, i.e. male and female are joined end-to-end with the male genitalia twisted through 180° (Gauld & Bolton 1988). In the laboratory mating took 2-3 minutes. During copulation the female stands with her wings folded at rest, while males have their wings spread at about 45° and periodically fan them. After uncoupling, the female immediately moves away and the male remains in place, tapping its abdomen several times on the leaf surface before flying off.

Fecundity and oviposition

The number of eggs carried by virgin females ranged from 57 to 87, while egg number within these limits was positively correlated with both age and size of females ($r = 0.76$ and $r = 0.66$, $P < 0.05$). On landing, female *P. froggatti* move sideways over the surface of a leaf perpendicular to the mid vein, with this movement continuing until an oviposition site is chosen. The female saws into the leaf tissue for 5–10 sec, then remains stationary for 3–4 min while ovipositing. At this time the body and antennae are held at an angle of about 45° to the leaf and to the mid vein, possibly to position the egg so that the larva hatches in the direction towards the apex of the leaf. Once completed, the female rubs her abdomen over the position of the egg spot three or four times, possibly to seal the hole, and then moves away, either staying on the same leaf or moving to another leaf to oviposit. Eggs are generally laid close to the mid vein and along the length of the leaf, but not in the distal 20–30 mm. The small egg spots, about 0.8 mm in diameter, form raised globulous structures (egg-galls) on the surface of the leaf. The number of egg spots per leaf ranged from 7–170, with numbers over about 90 representing the ovipositions of more than one female.

Life-history stages

The morphology, colour and size of the egg, larval instars and pupa of *P. froggatti* are virtually identical to those described by Farrell & New (1980). Briefly, the egg is flattened and oval in shape, measuring 0.75×0.5 mm. There are five larval instars in the female and four in males. For the Adelaide population females had mean head capsule widths of 0.49 (I), 0.62 (II), 0.80 (III), 1.01 (IV) and 1.25 mm (V) ($n \geq 25$ in each case), with males being virtually identical to female instars I–IV. These sizes are almost identical to those measured for the Melbourne population by Farrell & New (1980), with the exception of female instar V which averaged 1.08 mm in the latter study. This discrepancy may be due to our selection of larvae from non-overlapping mines, where there was no competition for food between individuals. At room temperature in the laboratory during January and February (daily average about 23°C) larval development to cocoon initiation (i.e. including the prepupal period) took 15–18 days and the complete life-cycle about 30–35 days.

Pupation is preceded by a prepupal stage, distinguished from the last larval instar by a lighter-coloured head capsule. The prepupa moves away from the tight perimeters of the mine into a more central position where it begins to spin a thin ovoid cocoon. Silk is laid down from mandibular glands as it swings its head from side to side. The cocoon is attached to the mine floor and the leaf surface above by silk, and forms an annulus of creases in the blister tissue. The

period from cocoon initiation to adult emergence took about eight days in the laboratory for both sexes. Two to three days after cocoon formation the prepupal cuticle was shed revealing the eye spots and appendages of the developing pupa. By the fifth day the pupa became pigmented, at which stage the sex of individuals could be determined by the colour of the thorax and presence of the female ovipositor, the thorax of males being black and that of females orange. The pupa moulted on day seven into the preadult stage, which is characterised by having all the features of a fully formed adult. The body is completely pigmented and the wings, which begin to unfold, are frequently fanned within the mine to help them dry. On the eighth day an oval-shaped hole is cut in the top of the mine, and the wasp voids a green-grey meconium just before exiting or immediately afterwards. In the laboratory approximately 25% of adults died after failing to emerge from their mine. This mortality was highest for leaves containing multiple individuals.

Longevity and overwintering

To determine the optimal holding conditions for *P. froggatti* in the laboratory and determine the potential for the species to overwinter as adults, longevity of wasps was measured at various temperatures and combinations of mated or unmated females, with food and water supplied or not. The regressions of mean survival time against temperature were significant for the four combinations of virgin and mated females, with and without food and water supplied (Fig. 1). The slope of the regression for females with food was significantly different from those without food and water for both virgin ($F = 6.85$; d.f. = 2, 6; $P < 0.05$)

Fig. 1a) and mated females ($F = 47.4$; d.f. = 2, 5; $P < 0.05$ – Fig. 1b), but mating did not affect the survival of the females for either of the treatments with ($F = 4.5$; d.f. = 2, 5; $P > 0.05$) or without food and water ($F = 1.64$; d.f. = 2, 6; $P > 0.05$). In Figure 1b the data for mated females with food and water supplied at 10°C are excluded because of the breakdown of the temperature cabinet part way through the experiment. The longevity of females was increased when held at lower temperatures and when water and honey were supplied, but was not affected by mating. It is not known whether both water and honey were responsible for the increase in the survival rate of the females, as these factors were not tested separately. Possibly only water is required to prevent females from desiccating, and food is unimportant for longevity, though it may be necessary for increased fecundity.

The longest that adult females survived in the laboratory at temperatures below 10°C was 28 days. Hence, it seems unlikely that *P. froggatti* overwinters only as adults. A small number of occupied mines was found on trees in coastal suburbs of Adelaide during June and July, but at no other sites. It seems likely,

therefore, that some pupae continue developing in refuge areas until about mid winter and the subsequent adults remain quiescent for the rest of winter before ovipositing into leaves in late August or early September (see Fig. 2).

Mine development

First and 2nd instar larvae first mine towards the distal end of the leaf following the direction of the venation, but as they grow with each subsequent moult, the mine becomes progressively larger and circular or oval in shape. As observed by previous authors (Farrell & New 1980; Nuttall 1985; Kay 1986), mines generally follow along the mid-vein of the leaf and, when more than one larva is present, their mines often merge so that almost the whole leaf can become blotched. The largest number of larvae observed to complete development on a single large leaf was 21, so that any remaining eggs from the large numbers of ovipositions (see above) either died beforehand or were eaten by the first emerged larvae. Leaves supporting more than about 10 larvae often resulted in smaller adult wasps compared with leaves supporting fewer larvae. Other authors (Farrell & New 1980; Curry 1981) have reported *Phylacteophaga* as confining its development only to the top surface of a leaf. This was confirmed here for eucalypt species that have differently textured

dorsal and ventral surfaces, but for species with isolateral leaves (i.e. identical surfaces on leaves hanging vertically), mining was carried out on either side, sometimes resulting in individual larvae being separated only by the internal venation of the leaf.

Damage to trees

The levels of damage varied between infested trees and between individual sites, possibly because of differences in the tree species present, their size, age and health. Quantifying damage for these variables was beyond the scope of this study but casual observations in the field allow for some useful generalisations to be made. Trees which supported large numbers of *P. froggatti* mines were similar in several respects: they were usually small (<4 m tall), were often situated on roadsides, carparks, parklands or isolated groups in paddocks, and were usually sheltered to some degree from westerly winds. Possibly sheltered localities prevent adult wasps from being blown away from their host plant, since they are not strong fliers. Trees that became heavily damaged appeared healthy in the early stages of attack, in that they had dense lush foliage and did not appear to be stressed. As reported by Farrell & New (1980), damage is more severe towards the base of trees, particularly on low hanging branches. The apex region is usually not attacked, especially for trees above 4.5 m in height. In some suburban areas, where there were many young trees of the same species (1–2 m in height), damage often reached very high levels, causing leaf shedding and sometimes death of saplings. Well-established trees (>8 m high), were far less frequently attacked and, if so, were usually in close proximity to heavily infested young trees. Mines on such trees were generally confined to low hanging branches with semi-mature leaves.

Host range

The range of tree species attacked by *Phylacteophaga* spp. was compiled by reviewing previous studies, as well as surveying a wide range of trees in the Adelaide region during 1990–91. Trees in open situations, nurseries and gardens were examined, with those in the latter two areas being used to confirm species identification. The data presented in Table 1 show that at least 27 eucalypt species are susceptible to attack both in Australia and New Zealand, with most of these records being attributable to *P. froggatti*. In Australia the most widely infested species are *Eucalyptus botryoides*, *E. camaldulensis*, *E. citriodora*, *E. cladocalyx*, *E. ficifolia*, *E. globulus* and *E. grandis*. Also, several non-eucalypt species have been reported as hosts, but there is some doubt as to the accuracy of at least some of these accounts as they have mostly not been confirmed since the initial reports.

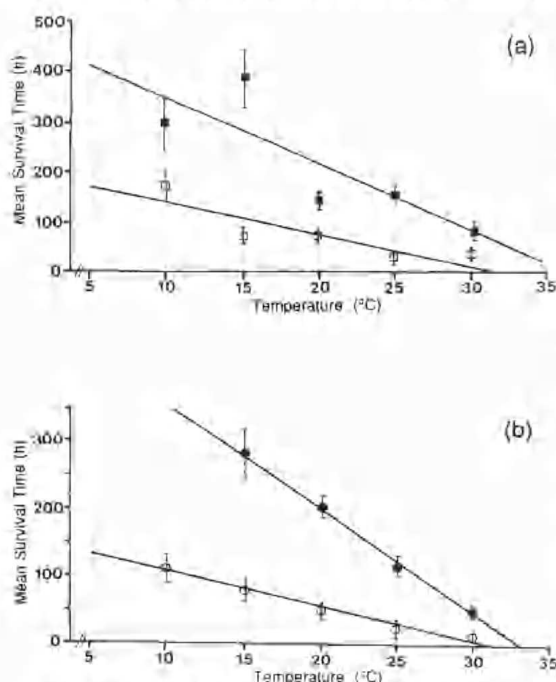


Fig. 1. Longevity of ♀ *Phylacteophaga froggatti* measured as the mean survival time for three replicates of 10 wasps (\pm S.E.) at different temperatures: (a) for virgin ♀♀ with food and water supplied (■) and without food and water (□); and (b) for mated ♀♀ with food and water supplied (●) and without food and water (○).

Parasitoid species

Over the period of this study 17 species of hymenopteran parasitoids were associated with *P. froggatti*. A list of these species and summary of their biology is presented in Table 2, and a key to their identification given in the Appendix. Eleven species were primary parasitoids of either the larval or pupal stages. Three were confirmed as facultative hyperparasitoids (*Elasmus australiensis* Girault, *Cirrospilus margiscutellum* (Girault) and *Eupelmus* sp.), while three have not had their biology conformed (*Lariophagus* sp., *Pediobius* sp. and *Chrysonotomyia* sp. 2). The species in this latter group were not positively reared from *P. froggatti*, but rather emerged into rearing containers with eucalypt leaves infested with host larvae. There is a possibility that these species had come from other leaf mining hosts, though none of the latter was seen after careful inspection of the

leaves. It is likely, therefore, that these three species are parasitoids of *P. froggatti*, but further study is required to confirm this.

Seasonality of Phylacteophaga froggatti and its parasitoids

Fortnightly field excursions from August 1990 to July 1991 to collect *P. froggatti* and parasitoids were used to determine the approximate seasonality of the species involved in the Adelaide region. Egg spots and early mine initiation were first evident on trees in the Adelaide Plains in late August 1990 and pupae and preadult stages in mines were present up until late May 1991. A few occupied mines were found in June and July on several trees, only in the western (coastal) suburban areas. Although relative abundance of species was not determined, it was clear from the number of infested leaves and trees that *P. froggatti* is most

TABLE 1. List of tree species which have been recorded in the literature and during this study as susceptible to damage by *Phylacteophaga* spp. (sources of information are as follows: 1, Anon. [1950] and 2, Moore [1966], coastal N.S.W.; 3, Riek [1955] and 4, Farrell & New [1980], Melbourne region, Vic.; 5, this project [1990-91], Adelaide region, S.A.; 6, Curry [1981], Perth region, W.A.; 7, Nuttall [1985] and 8, Kay [1986], New Zealand; sources 3-5, 7 and 8 are for *Phylacteophaga froggatti*).

Host Plant	Recorded <i>Phylacteophaga</i> damage							
	N.S.W.		Vic.		S.A.	W.A.	N.Z.	
	1	2	3	4	5	6	7	8
<i>Eucalyptus botryoides</i>	✓	✓		✓		✓	✓	✓
<i>E. camaldulensis</i>	✓				✓	✓	✓	
<i>E. cinerea</i>						✓	✓	✓
<i>E. citriodora</i>		✓			✓	✓	✓	
<i>E. cladocalyx</i>	✓	✓			✓	✓		
<i>E. diversicolor</i>						✓		
<i>E. ficifolia</i>	✓	✓				✓	✓	
<i>E. globulus</i>	✓	✓	✓			✓	✓	
<i>E. gomphocephala</i>						✓		
<i>E. grandis</i>			✓			✓		
<i>E. lehmanni</i>						✓		
<i>E. leucosylon</i>							✓	
<i>E. leucosylon rosea</i>					✓			
<i>E. longifolia</i>					✓			
<i>E. maculata</i>		✓						
<i>E. macarthurii</i>							✓	
<i>E. marginata</i>						✓		
<i>E. melliodora</i>						✓		
<i>E. nicholii</i>							✓	
<i>E. ovata</i>							✓	
<i>E. perrintana</i>		✓					✓	
<i>E. punctata</i>					✓			
<i>E. robusta</i>		✓				✓		
<i>E. rudis</i>					✓	✓		
<i>E. saligna</i>							✓	
<i>E. sideroxylon</i>		✓					✓	
<i>E. viminalis</i>							✓	
<i>Agonis flexuosa</i>								✓
<i>Betula</i> (Birch)								✓
<i>Lophostemon confertus</i> (Tristania) ..	✓			✓				✓
<i>Quercus palustris</i>							✓	
<i>Q. robur</i>							✓	

TABLE 2. Summary of the relationship between *Phylacteophaga froggatti* and its parasitoids in the Adelaide region (— = information not available; pa = preadult).

Species of Parasitoid	Family	Stage of <i>P. froggatti</i> attacked	Solitary (S) or Gregarious (G)	Endoparasitoid (N) or Ectoparasitoid (C)	Primary (P) or Hyperparasitoid (H)
<i>Bracon confusus</i>	Braconidae	larva; pupa	S	C	P
<i>Bracon phylacteophagus</i>	Braconidae	larva; pupa	S	C	P
<i>Paraphylax</i> sp.	Ichneumonidae	pupa	S	C	P
<i>Brachymeria</i> sp.	Chalcididae	pupa	S	N	P
<i>Elasmus australiensis</i>	Elasmidae	?pupa	S	C	P; H
<i>Apleurotropis</i> sp.	Eulophidae	larva	G	?N	P
<i>Chrysonotomyia</i> sp. 1	Eulophidae	larva	G	C	P
<i>Chrysonotomyia</i> sp. 2	Eulophidae	—	—	—	—
<i>Cirrospilus margiscutellum</i>	Eulophidae	larva; pupa; pa	S	C	P; H
<i>Cirrospilus occipitis</i>	Eulophidae	pupa	S	C	P
<i>Cirrospilus</i> sp. 3	Eulophidae	larva	S; G	C	P
<i>Cirrospilus</i> sp. 4	Eulophidae	—	S	C	P
<i>Cirrospilus</i> sp. 5	Eulophidae	pupa	S	C	P
<i>Diaulomorpha</i> sp.	Eulophidae	larva; pupa	G	C	P
<i>Pediobius</i> sp.	Eulophidae	—	—	—	—
<i>Eupelmus</i> sp.	Eupelmidae	pupa	S	C	P; H
<i>Lariophagus</i> sp.	Pteromalidae	—	—	—	—

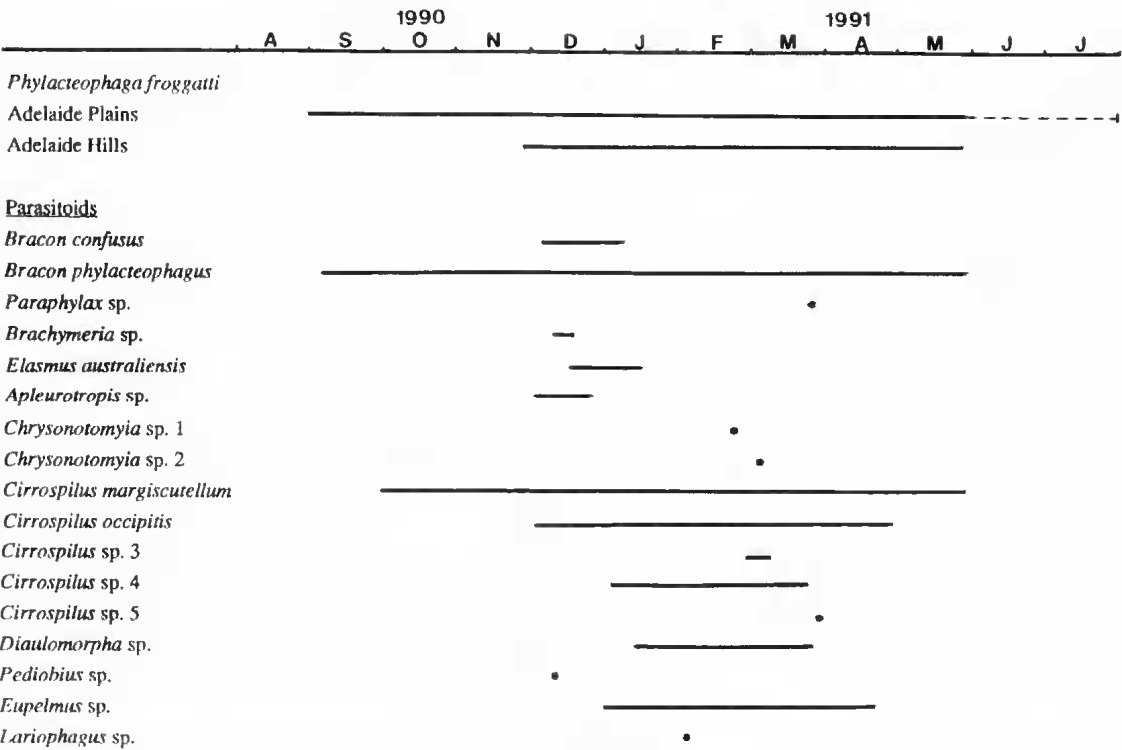


Fig. 2. Seasonality of *Phylacteophaga froggatti* and its parasitoids in the Adelaide region for 1990-91, determined by the presence of larvae and pupae in leafmines.

numerous at sites on the Adelaide Plains from about early December to late March (Fig. 2), and that there are three, possibly four, peaks in numbers over the period September to March. In the Lobethal-Woodside area (Adelaide Hills), largest numbers occurred slightly later, from about early January to late March, with egg spots and mine initiation not appearing until later November, presumably because of the cooler average temperatures there compared with the Adelaide Plains.

Of the 17 species of parasitoids, six were encountered over a period of two months or more (i.e. *Bracon phylacteophagus* Austin, *Cirrospilus margiscutellum*, *C. occipitis* Girault and *Cirrospilus* sp. 4, *Eupelmus* sp. and *Dialomorpha* sp.) (Fig. 2), and of these (in descending order) *C. margiscutellum*, *B. phylacteophagus*, *Eupelmus* sp. and *Dialomorpha* sp. were reared in the largest numbers. No parasitised hosts or parasitoid pupae were found in mines during July and August, though two adult female *B. phylacteophagus* and one *C. margiscutellum* were located in old mines during this time, indicating that these and possibly all parasitoids in the *P. froggatti* complex overwinter quiescently as adults.

Levels of parasitism

Collections of mined larvae during January and February 1991 enabled assessment to be made of the levels of parasitism in the field at three separate sites, viz., Lobethal (Adelaide Hills), Sturt and Dover Gardens (Adelaide Plains) (Table 3). These data show a large range in the level of parasitism of *P. froggatti* (15.6 to 60.3%), and in all cases *C. margiscutellum* was by far the most important parasitoid. Other parasitoids contributed 0 to 11.5% of total parasitism, of which *B. phylacteophagus* was most common. These data, however, represent a minimum estimate of percentage parasitism, particularly for the Sturt sample, where *P. froggatti* were mostly represented by early life-history stages when collected, so that those sampled could have been parasitised if left in the field. Because *C. margiscutellum* is capable of paralysing and feeding on all stages of *P. froggatti* from early instars to the preadult stage, an estimate of the maximum potential parasitism was obtained by adding the measured level of parasitism with the proportion of hosts still viable.

Biology of parasitoid species

Family Ichneumonidae

Paraphylax sp.

FIG. 5

There are more than 50 recognised species of *Paraphylax* from Australia, the majority of which are undescribed (Gauld 1984). Where their biology is known, they have been recorded mostly as primary

ectoparasitoids and hyperparasitoids of lepidopteran hosts. The single male specimen reared here in March 1991 is an ectoparasitoid of *P. froggatti* larvae. It belongs to the *covax* species-group, and is probably the same species as that recorded by Gauld (1984) from *P. froggatti* in south-eastern Australia. Being the only ichneumonid in this parasitoid complex, *Paraphylax* sp. can be easily identified by its characteristic wing venation.

Family Braconidae

Bracon confusus Austin & *B. phylacteophagus* Austin FIGS 3, 4, 6.

Both these species are solitary primary ectoparasitoids of third instar larvae to early stage pupae of *P. froggatti* (Table 2). *B. phylacteophagus* was the more commonly encountered species of the two, and was found associated with its host for the same period that occupied mines were present in the field (September to May). *B. confusus* was collected for only a short period during December-January. The biology of these species has been discussed by Austin & Faulds (1989) and Faulds (1990) and only observations complementary to those given by these authors are presented here. Prior to 1989, references to *Bracon* associated with *Phylacteophaga* did not recognise the presence of two sympatrically occurring species.

B. confusus and *B. phylacteophagus* oviposit one egg, rarely two, in a mine, either next to or onto the surface of the host. The host larva is paralysed at oviposition, thereby allowing the secure attachment of a newly emerged *Bracon* larva in the absence of an active host which normally whips its abdomen about when disturbed. Late stage *Bracon* larvae are easily distinguished from other parasitoids by their large size, dorsal ampullae and covering of long hairs, but they are identical to each other. Contrary to the findings of Farrell & New (1980), most larvae which we gently dislodged from a host with a fine brush did not die, but rather successfully reattached themselves. When feeding is completed, *Bracon* larvae normally move away from their host before commencing cocoon construction but occasionally pupate inside their host's pupal cocoon. When spun away from a host pupa, *Bracon* cocoons often have loose frass and moulted cuticles incorporated into their silk matrix. They are white in colour, ovoid in shape and measure about 7.0×1.3 mm. The confined prepupa deposits a meconium at one end of its cocoon and then bunches into the opposite end so that it occupies only about half of the internal space. Adults emerged in the laboratory 11-12 days after the commencement of cocoon construction. Adult *B. phylacteophagus* held at constant 15°C were still alive after 68 days and individuals were observed to feed on the honey and water provided.

Along with *Paraphylax* sp., *B. confusus* and *B. phylacteophagus* can be easily recognised by their relatively complete venation and large size (<3 mm), and the species separated by their colour and differences in pilosity.

Family Chalcididae

Brachymeria sp.

FIG. 7

This genus is a moderately large genus in Australia comprising primary parasitoids and obligatory hyperparasitoids of the pupae of a great range of holometabolous insects, but particularly Lepidoptera (Bouček 1988). The species recorded here was reared from several pupae of *P. froggatti* during one week in December 1990. *Brachymeria* sp. is easily identified by its small robust form, enlarged hind femur, elongate postmarginal vein, and densely punctate dorsal mesosoma.

Family Eupelmidae

Eupelmus sp.

FIG. 8

This species was generally reared as a solitary primary parasitoid from the pupal stage of its host, but on several occasions was also found to be hyperparasitic on smaller conspecific larvae and those of several other unidentified parasitoids. Mature larvae can be identified from the other common parasitoids in mines by the presence of dorsal ampullae and dense, long hairs on the thoracic segments. *Eupelmus* sp. was reared from *P. froggatti* from mid summer to mid autumn. Adults can be separated from the other species in the complex by the presence of a greatly enlarged mesopleuron, exposed ovipositor, and form of the wing venation.

Family Elasmidae

Elasmus australiensis Girault

FIG. 9

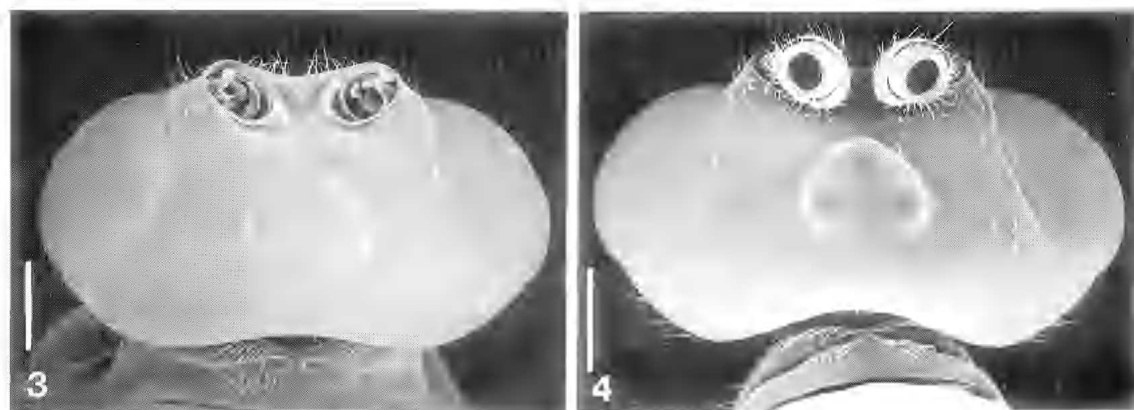
This species was reared either as a solitary primary ectoparasitoid or hyperparasitoid of *P. froggatti* during December and January. Previous reports (Riek 1967; Austin & Allen 1989; Allen 1990) have recorded this species as being gregariously hyperparasitic on ichneumonid pupae associated with the lepidopteran defoliator *Uraba lugens* Walker. It can be readily identified by its large disc-shaped hind coxa, cream coloured legs with black hairs and spines, and distinctive criss-cross pattern of black hairs on the hind tibia. See Riek (1967) for additional taxonomic information and list of synonyms.

Family Pteromalidae

Lariophagus sp.

FIGS 10, 11

According to Bouček (1988), this small genus is represented in Australia only by *L. distinguendus* (Foerster), a cosmopolitan parasitoid of beetles associated with stored grain. The single specimen reared here was removed in early February 1991 from a *P. froggatti* mine that did not contain any other parasitoids or other potential hosts. Given the paucity of biological information available on this genus we are unable to speculate further on this species. However, given that a dead *P. froggatti* larva was the only other occupant of the mine, we have assumed that *Lariophagus* sp. is either a primary or hyperparasitoid on it. This small nondescript species is the only pteromalid in the parasitoid complex and it can be best identified by the presence of five tarsal segments and six funicle segments of the antenna.



Figs 3, 4. Dorsal view of the head of ♀ *Bracon* spp.: 3, *Bracon phylacteophagus* Austin; 4, *Bracon confusus* Austin. Scales = 250 µm.

Family Eulophidae

Pediobius sp.

FIG. 12

Members of this genus are known to be primary and hyperparasitoids of eggs, pupae and sometimes larvae of various insects, mainly of Lepidoptera, Coleoptera, Diptera and other Hymenoptera, with several species being reported as attacking leaf-miners (Bouček 1988). An unidentified *Pediobius* species is hyperparasitic on *U. lugens* (Austin & Allen 1989; Allen 1990), the latter occasionally appearing on the same host plants as *P. froggatti*. However, variation in sculpturing on the scutellum indicates that the *Pediobius* associated with these two hosts are different species. Previously, *P. bruchicida* (Rondani), a gregarious species (Bouček 1988), has been found as a hyperparasitoid on *B. phylactophagus* in New Zealand (Faulds 1990), and this species resembles closely the single specimen recorded here. *Pediobius* sp. was reared in a container from a number of leaves mined in late December 1990. Inspection of these leaves revealed the presence of no other potential hosts. Like *Apleurotropis* sp. and *Diallomorpha* sp., this species can be identified from others in the complex by the presence of several long hairs on the scutum and scutellum, and the posterior expansion of the scutellum. In addition to the characters in the key, it can be separated from *Apleurotropis* sp. by the absence of a postero-medial sulcus on the scutum and from *Diallomorpha* sp. by the very distinctive colour of the latter species.

Apleurotropis sp.

FIG. 13

This genus has previously been recorded as emerging from *P. froggatti* mines (Rick 1955; Farrell & New 1980), with Bouček (1988) listing *A. unnotipennis* (Girault) as parasitising *P. eucalypti* in the Melbourne area. Material reared over a three week period in December 1990 here confirms that this species is gregarious, with the larvae probably being endoparasitic, as holes were found in the body of the host next to the parasitoid pupae. A single mine of a late stage *P. froggatti* larva was found to contain 12 parasitoid larvae and pupae, of which most completed development in the laboratory. Compared with *Pediobius* sp., this species can be easily recognised by the presence of a large postero-medial sulcus on the scutum (see above).

Diallomorpha sp.

FIGS 14, 15

This gregarious primary ectoparasitoid attacks the larvae and pupae of *P. froggatti*, with up to 10 parasitoids being recorded from a single mine. At room

temperature most individuals in a single mine emerged within 13 days after the commencement of pupation. Mature larvae can be easily recognised from the other common parasitoids in the complex because of their gregarious behaviour and absence of dorsal ampullae. Adults can be recognised by their metallic green-gold colour, white legs and light brown antennae (see comments under *Pediobius* sp.). An apparently undescribed species belonging to this genus has been recorded from *Phylactophaga* mines in Western Australia and elsewhere in Australia (Bouček 1988), and this may be the same species as reared here.

Chrysonotomyia sp. 1 and sp. 2

FIGS 16, 17

According to Bouček (1988), members of this medium-sized genus of about 40 described Australian species, develop in the eggs or young larvae of leaf-mining and gall-forming Diptera and Lepidoptera. Virtually no biological information is available for any Australian species, except for one reared from *Perthida glyphopa* Common (jarrah leaf-miner) in the warmer regions of the Darling Ranges and coastal regions of south-west Western Australia (Mazanec 1988). It is a solitary endoparasitoid most frequently of the 2nd and 3rd instar larvae.

Two species belonging to this genus have been associated with *P. froggatti* in the Adelaide region. *Chrysonotomyia* sp. 1 was reared as a gregarious primary ectoparasitoid of a single late stage larva of *P. froggatti* collected at Lobethal in March 1991, while two specimens of *Chrysonotomyia* sp. 2 were reared only from mined leaves in February 1991 collected at the Dover Gardens site, and therefore are only tentatively assumed to be parasitic on this host. Although very small in size (about 1 mm in length), these two species can be separated from the other eulophid genera in the complex by the antennal funicle being only 2-segmented and the scutellum lacking a submedial groove. They can be separated from each other by the form of the wing venation and their colour.

Cirrospilus margiscutellum (Girault)

FIGS 18, 19, 22

Cirrospilus is a large and taxonomically difficult genus of small often brightly patterned wasps which are well-known primary and hyperparasitoids of eucalypt leaf-mining insects. Two described species have previously been reared from *Phylactophaga* spp., viz., *C. margiscutellum* (Girault) from Western Australia and *C. occipitis* Girault from N.S.W. (Bouček 1988), while undetermined species have been reared from *P. froggatti* in Melbourne by Rick (1955) and Farrell & New (1980) and in Western Australia by

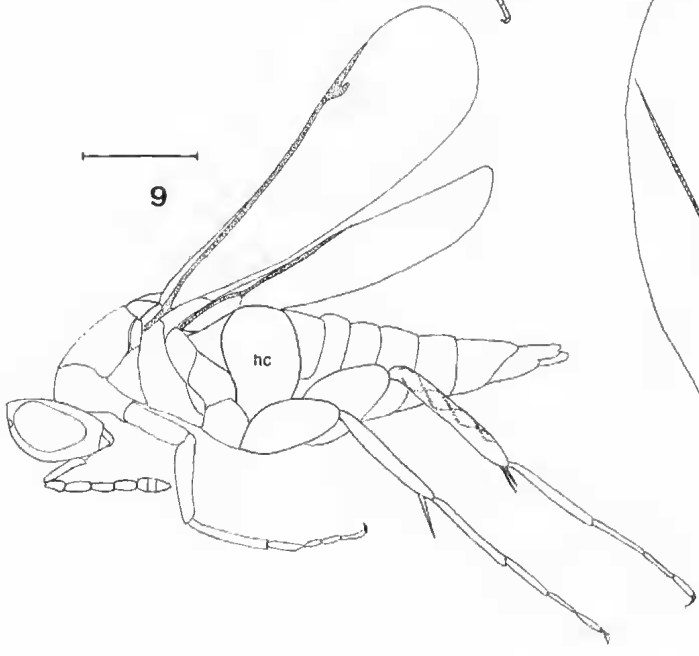
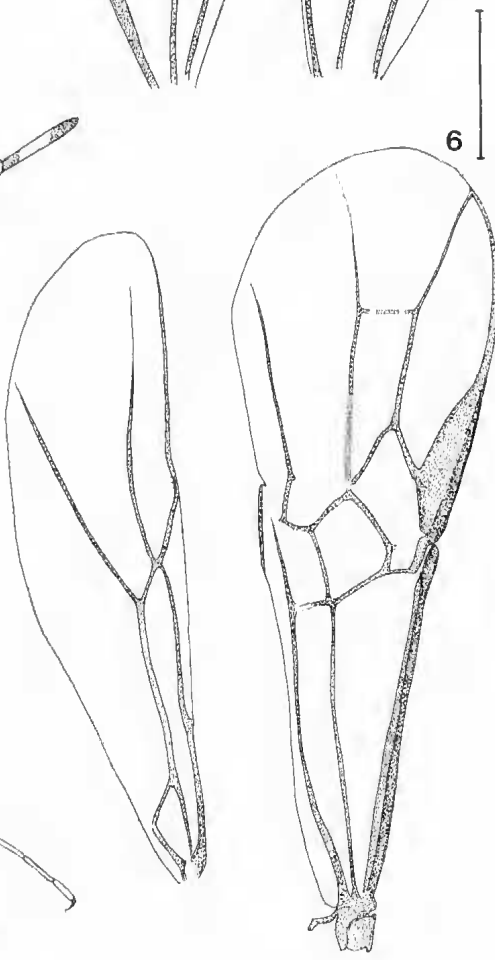
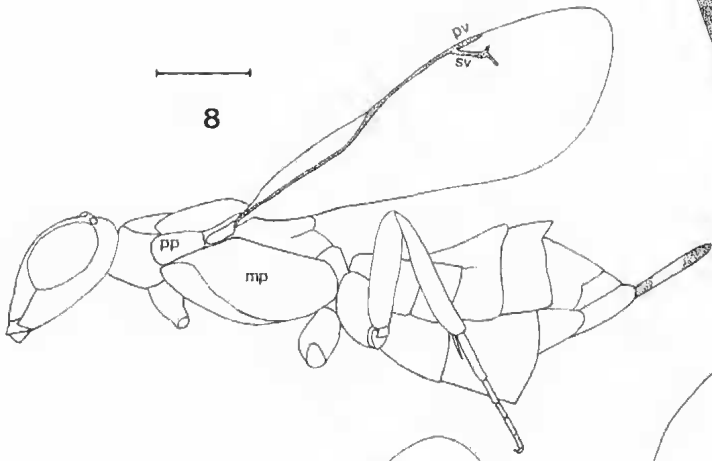
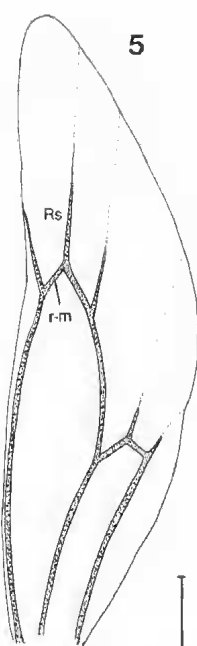
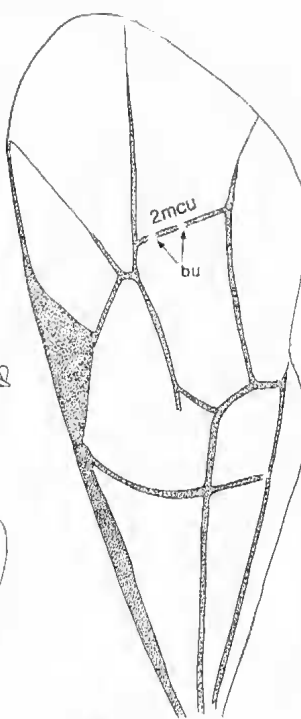
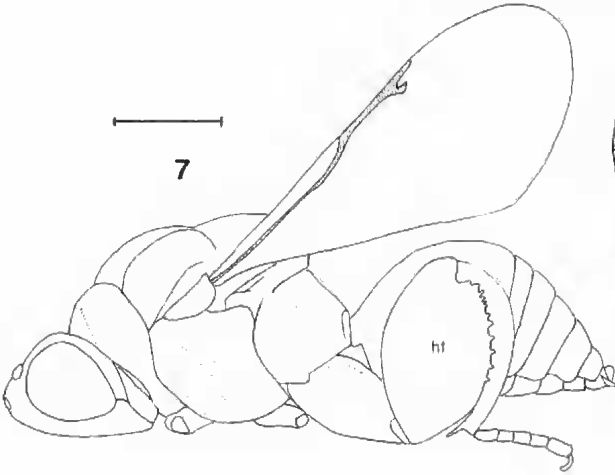


TABLE 3. Mortality of *Phylactephaga froggatti* as revealed by collections made during January and February 1991, from Lobethal where trees were in relatively early stages of attack, and from Sturt and Dover Gardens where trees had been heavily attacked during the preceeding weeks (— = information unavailable).

	Collection Sites		
	Lobethal	Sturt	Dover Gardens
Total number of mines examined	434	899	410
% already emerged	45.6	0	1.2
Viable <i>P. froggatti</i>			
% larvae, pupae & preadults	13.8	79.6	6.3
Cause of Death Unknown			
% larvae and pupae	10.1	—	—
% preadults	10.6	—	—
% Total	20.7	3.8	21.0
Parasitism			
% parasitized by			
<i>Cirrospilus margiscutellum</i>	13.8	15.5	60.7
% parasitized by <i>Bracon</i> spp.	1.6	0	0
% parasitized by others	0.2	1.1	0
% Total parasitism	15.6	16.6	60.7
% max. potential parasitism	29.4	96.2	67.0

Curry (1981). Clearly, at least some *Cirrospilus* spp. are widespread in Australia. Here we record *C. margiscutellum* from the Adelaide region and *C. occipitis* from Perth (material in ANIC) for the first time, indicating that these species are distributed across the southern part of the continent, at least.

C. margiscutellum was by far the most commonly reared parasitoid associated with *P. froggatti* in the Adelaide region (Table 3), and was present in mines for nearly the whole time that host larvae and pupae were available (late September to late May). As shown by Farrell & New (1980), laboratory observations confirm it to develop as a solitary primary parasitoid of third instar larvae to late stage pupae, as well being hyperparasitic, in the Adelaide region, on the larvae of *Bracon* spp., *Eupelmus* sp., *Diaulomorpha* sp. and small conspecific larvae occurring in the host mine. When multiple *P. froggatti* were found in mines, with some parasitised by *Bracon* spp., the latter appeared to be preferentially parasitised by *C. margiscutellum* rather than unparasitised primary hosts.

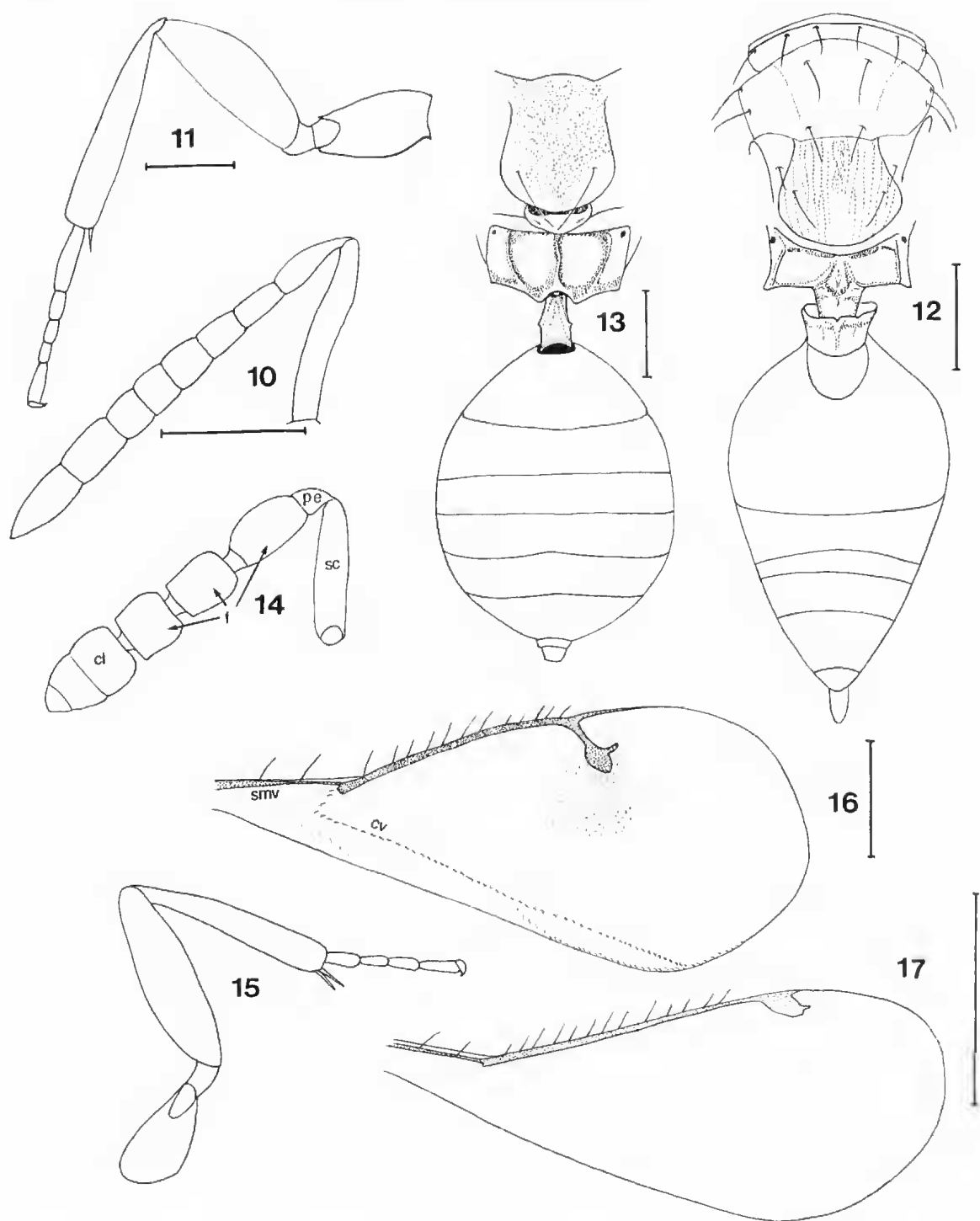
Usually only one *Cirrospilus* larva was found feeding on a host and generally it did not confine its feeding to one feeding site, as indicated by numerous dark melanised spots found over the host's integument. In the laboratory, *C. margiscutellum* held at room temperature took 16-17 days to complete development, once emerged from the egg. Mature *Cirrospilus* larvae

could be recognised from those of the other common parasitoids in the complex by the absence of long setae over the body and the presence of ampullae on both the dorsal and ventral surfaces. The larvae of different species of *Cirrospilus* could not be separated. Adults of *Cirrospilus* spp. can be distinguished from other eulophids in the complex by the presence of a submedial groove on the scutellum, submarginal vein with at least two bristles, and their metallic and/or striking colour patterns. *C. margiscutellum* is the only member of the genus in this complex to have the face with transverse black bands.

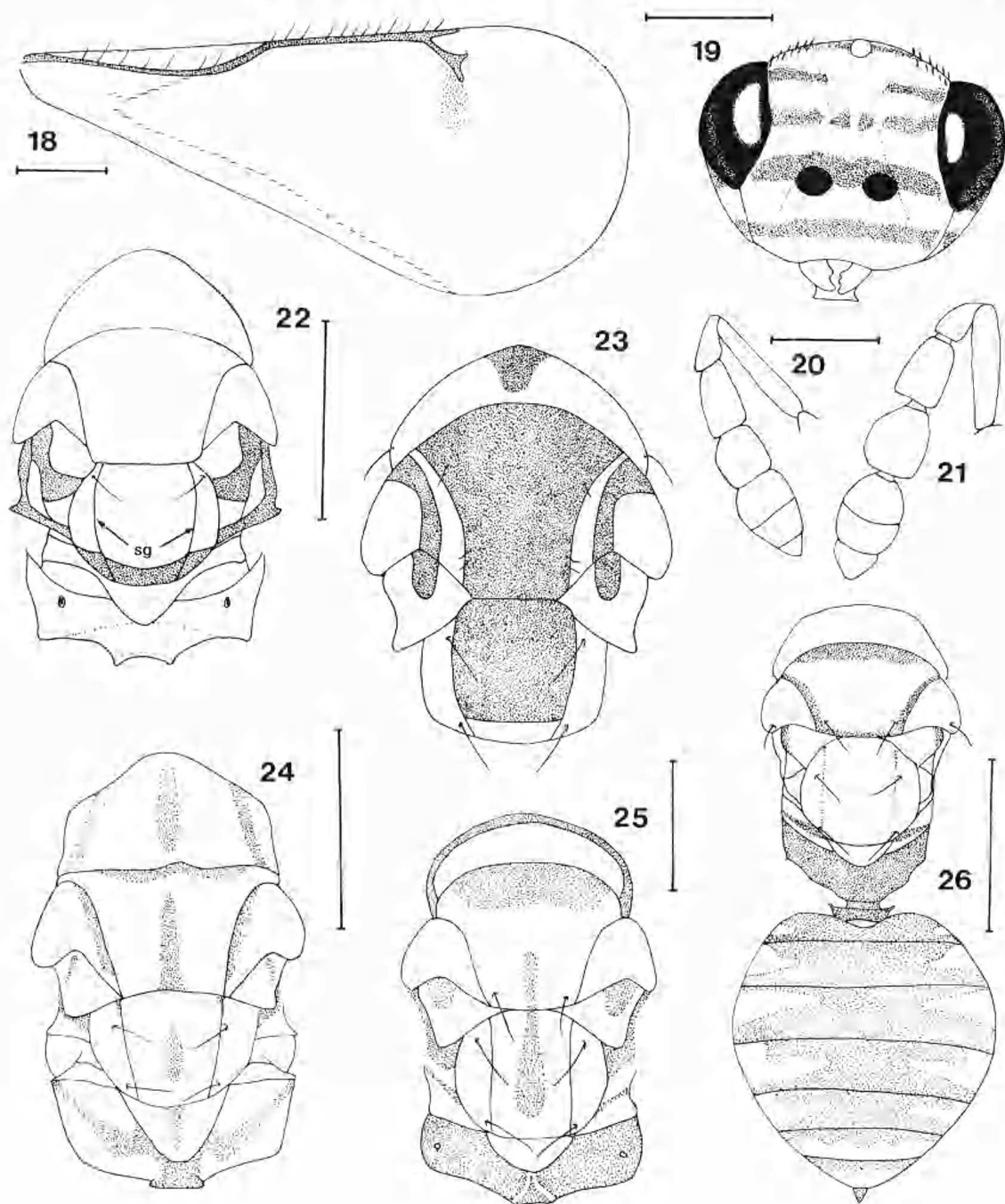
C. occipitis Girault & *Cirrospilus* sp. 3-5 FIGS 20, 21, 23-26

Four other species of *Cirrospilus* were reared from *P. froggatti* mines, all of which are solitary primary ectoparasitoids, with the exception of *Cirrospilus* sp. 3 which was found to be gregarious. *C. occipitis* and sp. 5 were observed to feed on host pupae, and sp. 3 and sp. 4 on the larval stages. *C. occipitis* and sp. 4 were found in mines over the summer months, early December to late March, and early January to late March, respectively, while sp. 3 and sp. 5 were recorded from only a few samples in one week in early March and late March, respectively. The five species encountered here can be separated relatively easily by their distinctive colour patterns.

Figs 5-9. 5-6, Fore and hind wings; 5, *Paraphylax* sp.; 6, *Bracon confusus* Austin. ♀; 7-9, Lateral view of whole body: 7, *Brachymeria* sp.; 8, *Eupelmus* sp.; 9, *Elasmus australiensis* Girault. Scales: Figs 5, 6 = 1.0 mm; Figs 7-9 = 0.5 mm. Abbreviations: bu = bullae; hc = hind coxa; hf = hind femur; mp = mesopleuron; pp = prepectus; pv = postmarginal vein; sv = stigmal vein.



Figs 10-17. 10-11, *Lariophagus* sp.: 10, antenna; 11, hind leg; 12, *Pediobius* sp., dorsal view of mesosoma and metasoma; 13, *Apleurotropis* sp., dorsal view of scutellum, propodeum and metasoma; 14-15, *Diaulomorpha* sp.: 14, antenna; 15, hind leg; 16-17, Fore wings: 16, *Chrysonotomyia* sp. 1; 17, *Chrysonotomyia* sp. 2. Scales: Figs 10, 14 = 0.5 mm; Figs 11, 15 = 0.5 mm; Fig. 12 = 0.5 mm; Fig. 13 = 250 μ m; Fig. 16 = 200 μ m; Fig. 17 = 0.5 mm. Abbreviations: cl = clava; cv = cubital vein; f = funicular segments; pe = pedicel; sc = scape; smv = submarginal vein.



Figs 18-26. 18-19, *Cirrospilus margiscutellum* (Girault): 18, fore wing; 19, anterior view of head showing transverse banding; 20-21, antennae; 20, *Cirrospilus occipitis* Girault; 21, *Cirrospilus* sp. 4; 22-25, *Cirrospilus* spp., dorsal view of mesosoma showing colour pattern: 22, *Cirrospilus margiscutellum* (Girault); 23, *Cirrospilus occipitis* Girault; 24, *Cirrospilus* sp. 3; 25, *Cirrospilus* sp. 4; 26, *Cirrospilus* sp. 5, dorsal view of mesosoma and metasoma showing colour pattern. Scales: Figs 18, 19 = 0.5 mm; Figs 20, 21 = 200 μ m; Figs 22, 23 = 0.5 mm; Figs 24, 25 = 250 μ m; Fig. 26 = 0.5 mm. Abbreviation: sg = submedial groove on scutellum.

Key to the parasitoids of *Phylacteophaga froggatti* in the Adelaide region (based on females)

1. Fore wing with more than one enclosed cell (Figs 5, 6); prepectus absent 2
Fore wing with no more than one enclosed cell (Figs 7, 16-18); prepectus usually present (Figs 8-9); sometimes absent (Fig. 7) (Chalcidoidea) 4
2. Fore wing with vein 2m-cu present; hind wing with vein r-m meeting Rs after Rs diverging from Sc + R (Fig. 5) (Ichneumonidae) [fore wing with two bullae in 2m-cu (Fig. 5); mesoscutum smooth and unsculptured] *Paraphylus* sp.
Fore wing with vein 2m-cu absent; hind wing with vein r-m meeting Rs before Rs diverging from Sc + R (Fig. 6) (Braconidae) 3
3. Vertex, occiput and temples mostly hairless except for row of short hairs around margin of eyes and posterior vertex (Fig. 3); propodeum black *Bracon phylacteophagus* Austin
Vertex, occiput and temples sparsely covered with long hairs (Fig. 4); propodeum orange-yellow *Bracon confusus* Austin
4. Hind femur enlarged and with teeth on ventral edge (Fig. 7); prepectus very small, virtually absent (Chalcidoidea) [malar suture distinct; postmarginal vein longer than stigmal vein (Fig. 7); propodeum with rough alveolate sculpturing] *Brachymeria* sp.
Hind femur not enlarged and without teeth (Figs 8, 11); prepectus distinct (Figs 8, 9) 5
5. Mesopleuron greatly enlarged, convex, developed into a large undivided shield (Fig. 8) [postmarginal vein slightly shorter than stigmal vein; ovipositor protruding from posterior metasoma, sheaths black with middle third white (Fig. 8)] *Eupelmus* sp.
Mesopleuron not greatly enlarged (Fig. 9) 6
6. Hind coxa developed as a large flat disc (Fig. 9); hind tibia with setae forming distinct criss-cross pattern; fore wing narrow; postmarginal vein much longer than stigmal vein (Fig. 9) (Elasmidae) [body dark, tegula and legs pale except for hind coxae] *Elasmus australiensis* Girault
Hind coxa not as a large flat disc (Fig. 11); hind tibial hairs not forming criss-cross pattern; fore wing relatively broad (Figs 16-18) 7
7. Hind tarsi 5-segmented (Fig. 11); antenna without distinct funicular segments and clava (Fig. 10) (Pteromalidae) [head round in anterior view; basal third of fore wing virtually devoid of hairs] *Lariophagus* sp.
Hind tarsi 4-segmented (Fig. 15); antenna with distinct funicular segments and clava (Figs 14, 20, 21) (Eulophidae) 8
8. Dorsal mesosoma with long stout hairs (Fig. 12); metasoma distinctly petiolate (Figs 12, 13); body black and shiny 9
If dorsal mesosoma with hairs then mostly fine and short; metasoma sessile, or petiole less conspicuous (Fig. 26); body colour variable 10
9. Scutellum longitudinally strigose with exception of longitudinal medial line which is smooth (Fig. 12); T1 of metasoma with anterior flange (Fig. 12); legs all black except proximal 3 tarsal segments of mid and hind legs which are white *Pediobius* sp.
Scutellum with coriaceous sculpturing (Fig. 13); T1 of metasoma without flange (Fig. 13); all legs distal to coxae pale in colour *Apleurotropis* sp.
10. Funicle of antennae 3-segmented (Fig. 14) [body metallic green-gold in colour, all legs distal to coxae white; body about 2 mm in length] *Dialtomorpha* sp.
Funicle of antennae 2-segmented (Figs 20, 21) 11
11. Scutellum without submedial grooves; submarginal vein with 2 dorsal bristles (Figs 16, 17); body less than 1 mm in length (*Chrysonotomyia* Ashmead) 12
Scutellum with submedial grooves (Figs 22, 23); submarginal vein with more than 2 dorsal bristles (Fig. 18); body greater than 1 mm in length (*Cirrospilus* Westwood) 13
12. Cubital vein of fore wing indicated by a single row of hairs (Fig. 16); stigmal vein distinct and infusate around distal end (Fig. 16); mesosoma and head metallic green *Chrysonotomyia* sp. 2
Cubital vein of wing not indicated (Fig. 17); stigmal vein short and not infusate (Fig. 17); mesosoma and head non-metallic and dark in colour *Chrysonotomyia* sp. 1
13. Clava of antenna continuous with funicular segments (Fig. 20) 14
Clava separated from funicular segments by distinct constriction between segments (Fig. 21) 16
14. Stigmal vein infusate around distal end, sometimes only faintly (Fig. 18); vertex with short stout black hairs (Fig. 19) 15
Stigmal vein without infuscation distally; vertex with only fine pale hairs [mesosoma with yellow and metallic green markings (Fig. 23)] *Cirrospilus occipitis* Girault
15. Dorsal mesosoma metallic green-blue with slight yellow markings in posterior half (Fig. 22), surface with reticulate sculpturing; face with transverse dark stripes (Fig. 19); pronotum shorter than scutum (Fig. 22) *Cirrospilus marginellum* (Girault)
Pronotum yellow with 3 longitudinal black bands, rest of mesosoma orange with black markings (Fig. 24); surface with coriaceous sculpturing; pronotum nearly as long as scutum *Cirrospilus* sp. 3
16. Metasoma rounded in dorsal view; pronotum yellow-orange, rest of dorsal mesosoma orange with black markings (Fig. 26) *Cirrospilus* sp. 5
Metasoma broadly elongate, pointed posteriorly; dorsal mesosoma yellow with black markings (Fig. 25) *Cirrospilus* sp. 4

Discussion

This study confirms a number of aspects of the biology of *P. froggatti* first reported by Farrell & New (1980), as well as documenting the fecundity and longevity of adults, and details of its parasitoid complex for the first time. Previously, this insect had been recorded only as a sporadic pest of eucalypts in the Adelaide region and then mostly on ornamental trees. However, the status of *P. froggatti* as an emerging serious pest both in Australia and New Zealand has increased dramatically over the last few years and this is correlated with a corresponding expansion in native woodland plantings in south-eastern Australia. Indeed, the Engineering & Water Supply Department of South Australia has rated *P. froggatti* as one of the most important pests at its Bolivar woodland (pers. comm. S. Shaw).

During this study we recorded nearly three times the number of parasitoid species associated with *P. froggatti* as any reported by previous authors (Riek 1955; Farrell & New 1980; Curry 1981). The size of the parasitoid complex in the Adelaide region, however, is unlikely to be significantly larger than elsewhere in

Australia. Rather, the concentration of this study on rearing parasitoids and its longer duration has meant that several rarer species have been collected. Also, the taxonomy of the groups involved is now better known (see in particular Bouček 1988 and Austin & Faulds 1989), so that species can be more easily and reliably identified. However, the makeup of the parasitoid complex and relative abundance of species does seem to differ between regions. For instance, in the Adelaide region *Cirrospilus* sp. 1 was far more abundant than *B. phylacteophagus*, while in Melbourne the latter species was more abundant (Farrell & New 1980). In Western Australia Curry (1981) reared six parasitoids from *Phylacteophaga* (three *Cirrospilus* spp., *Elasmus* sp., *Eupelmus* sp., an unnamed eulophid and *Apanteles* sp.) but no *Bracon*. Austin & Faulds (1989) have pointed out that the record of *Apanteles* sp. must be erroneous as members of this genus and all microgastrine braconids are endoparasitoids of lepidopteran larvae. The only major parasitoid taxon not recorded in this study is *Isophluoides westralianus* Girault, a pieromalid, which has been reared from *P. froggatti* only in Western Australia (Bouček 1988).

Farrell & New (1980) suspected the *Cirrospilus* sp. reared by them in Melbourne to be polyphagous and to use alternative hosts at different times of the year to breed continuously. Although we did not rear

parasitoids from other eucalypt leaf minings in the Adelaide region, the fact the multiple *Cirrospilus* species have often been recorded from other hosts does provide some indirect evidence that members of this parasitoid genus are polyphagous (pers. comm. N. Gough, I. D. Naumann).

This study should provide a solid basis for more detailed work on the ecology of *P. froggatti*, particularly the factors that influence its abundance, means of overwintering, and the susceptibility of its eucalypt species. These and other factors will be important in understanding how *P. froggatti* develops as a pest and how best it can be controlled. Programs aimed at limiting the damage caused by this sawfly will need to take into account the mortality caused by the above parasitoids. In this respect future research might profitably examine both seasonal and regional differences in rates of parasitism and the species involved.

Acknowledgments

We thank Dr John LaSalle, International Institute of Entomology, London for confirming the identity of the chalcidoid parasitoids, and Mr Paul Dangerfield for the line drawings, electron micrographs, and his comments on the manuscript.

References

- ANON (1950) The leaf blister sawfly — *Phylacteophaga eucalypti*. *The Agricultural Gazette* 470-471.
- ALLEN, G. R. (1990) *Uraba lugens* Walker (Lepidoptera: Noctuidae): larval survival and parasitoid biology in the field in South Australia. *J. Aust. ent. Soc.* 29, 301-312.
- AUSTIN, A. D. & ALLEN, G. R. (1989) Parasitoids of *Uraba lugens* Walker (Lepidoptera, Noctuidae) in South Australia, with description of two new species of Braconidae. *Trans. R. Soc. S. Aust.* 113, 169-184.
- & FAULDS, W. (1989) Two new Australian species of *Bracon* F. (Hymenoptera: Braconidae) parasitic on *Phylacteophaga* spp. (Hymenoptera: Pergidae). *J. Aust. ent. Soc.* 28, 207-213.
- BENSON, R. B. (1963) Some new Western Australian sawflies of the Euryinae and Phylacteophaginae (Hymenoptera: Pergidae). *J. Roy. Soc. W. Aust.* 46, 81-84.
- BUNGEY, R. (1986) Insect pests, pp. 233-241. In Wallace, H. R. (Ed.), "The Ecology of the Forests and Woodlands of South Australia." (Govt. Printer, Adelaide).
- BOUČEK, Z. (1988) "Australasian Chalcidoidea (Hymenoptera). A Biosystematic Revision of Genera of Fourteen Families, with a Reclassification of Species." (CAB International, Wallingford).
- CURRY, J. S. (1981) Native wasps hit introduced tree pest. *J. Agric. W. Aust.* 22, 61-62.
- FARRELL, G. S. & NEW, T. R. (1980) Some aspects of the biology of the eucalypt-mining sawfly *Phylacteophaga froggatti* Rick (Hymenoptera: Pergidae). *Aust. J. Zool.* 28, 83-90.
- FAULDS, W. (1990) Introduction into New Zealand of *Bracon phylacteophagus*, a biocontrol agent of *Phylacteophaga froggatti*, *Eucalyptus* leaf-mining sawfly. *N. Z. J. Forest Sci.* 20, 54-64.
- FROGGATT, W. W. (1899) A new genus and species of sawfly. *Proc. Linn. Soc. N.S.W.* 24, 130-134.
- GAULD, I. D. (1984) "An introduction to the Ichneumonidae of Australia." (British Museum [Natural History] London).
- & BOLTON, B. (Eds) (1988) "The Hymenoptera." (British Museum [Natural History], London and Oxford University Press, Oxford).
- KAY, M. K. (1986) *Phylacteophaga froggatti* Rick (Hymenoptera: Pergidae) *Eucalyptus* leaf mining sawfly. *Forest and Timber Insects in New Zealand*, No. 64.
- MAZANEC, Z. (1988) Immature stages and life history of *Chrysotomyia* sp. (Hymenoptera: Eulophidae), a parasitoid of the jarrah leafminer. *J. Aust. ent. Soc.* 27, 279-292.
- MOORE, K. M. (1966) Observations on some Australian forest insects 22. Notes on some Australian leaf-miners. *Aust. Zool.* 13, 303-349.
- NAUMANN, I. D. (1983) A new genus of Phylacteophaginae from northern Australia with a key to the genera of the subfamily (Hymenoptera: Tenthredinoidea: Pergidae). *J. Aust. ent. Soc.* 22, 237-242.
- NUTTALL, M. J. (1985) New insect pest attacks eucalypts *Phylacteophaga froggatti* (Hymenoptera: Pergidae). *The New Zealand Farmer* 106, 124-5.
- RIEK, E. F. (1955) Australian leaf-mining sawflies of the genus *Phylacteophaga* (Hymenoptera: Tenthredinoidea). *Aust. J. Zool.* 3, 95-98.
- (1967) Australian Hymenoptera Chalcidoidea family Eulophidae, subfamily Elasmidae. *Ibid.* 15, 145-99.
- (1970) A redefinition of the subfamily Phylacteophaginae with description of a new genus and species (Hymenoptera: Symphyta: Pergidae). *J. Aust. ent. Soc.* 9, 215-218.